Nanosystem Design
Lecture 1: Introduction

Prof. R. Iris Bahar
EN291-S10

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Course Information

- Instructor: Iris Bahar
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- Office Hours: By appointment
- Course Webpage:
  http://www.lems.brown.edu/~iris/en291s10-05
  (soon to be up and running)

Course Format and Grading

- Seminar format: mix of lectures and discussion on assigned reading.
- Students are responsible for leading and participating in these discussions.
- Grading:
  - Discussion leadership: 20%
  - Quality of scribe: 20%
  - Class participation: 15%
  - Research project: 35%
  - Homework: 10%

Class Discussions

- Most classes will consist of a discussion of 1-2 papers on:
  - Nanotechnology
  - Alternative approaches to computing
- Class format
  - 1 discussion leader: keep discussion going, preparing presentation material
  - 2 scribes: create notes of the lecture. These will be posted on the webpage for all the class to access.
  - All students: be involved in active discussion

Project

- Projects will involve investigating some aspect of nanotechnolgy or non-conventional computing
- May be related to some topic discussed in class or something new.
- Expected to involve new research – not just a survey of previous work.
- Group projects are encouraged

What is this course about?

- A look at how improvements in silicon fabrication technology have shaped today's computer system designs.
- Understanding the limitations of today's silicon-based technology
- Exploring emerging nanotechnologies
- Understanding how these alternative technologies may impact future VLSI and computer architectures.

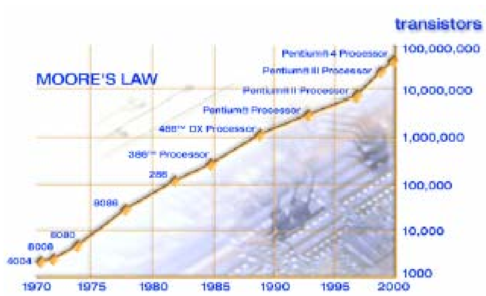
What about CS 295??

- Prof. Savage is offering a course on nanocomputing (Introduction to Nanocomputing)
- While some of the same topics will be covered in both courses, the emphasis will be different.
- EN291 will emphasize more of the device and design aspects of nanocomputing
- CS 295 will emphasize more of an analytical approach.
- Some students may wish to register for both courses.

Computing today

- Over the past decades, computer system performance has been driven by improvements in silicon fabrication technology.
- In 1973, Gordon Moor first made the prediction that the number of transistors on a chip would double every 18 months until fundamental physical limits are reached.

Moore’s Law in action



From http://www.intel.com/technology/moorslaw.htm

What next?

- Signs are that the rate of improvement cannot be sustained.
- Maintaining the exponential growth rate is becoming increasingly difficult.
- Will “conventional” silicon-based architectures need to be replaced with “unconventional” structures to maintain growth?

Conventional vs. Unconventional

- “Conventional” computer architecture
  - Uses stored-program model of computation
  - Implemented using silicon VLSI
- Unconventional computer architecture
  - ASICs
  - Reconfigurable devices
  - Quantum
  - Biological
  - Molecular Electronics

Stored-Program Model

- One of the key developments in early computing.
  - Also known as the “von Neumann” model

```
for (i=1;  i<10;  i++) {
    a = a * g(i);
}
```

⇒

```
01110110110110
11111011011011
01101000010110
10110101110110
10010110111010
```

The Stored-Program Model

- Treat programs as data
  - Load and store tem from disk
  - Programs can modify themselves
  - Programs can modify/create other programs
    - Assemblers
    - Compilers
    - debuggers
- Universal computing devices

Disadvantages of this Model

- Big complexity/computational power cost needed to provide flexibility
- A single application can rarely take advantage of all features available on these devices
- May still not be able to do specific tasks very efficiently.

Alternatives

- Dataflow
  - Instructions explicitly encode dependencies
  - Goal is to expose fine-grained parallelism
  - Really an alternate form of stored program
- Embedding Computation In Hardware
  - ASICs
  - Reconfigurable Logic

Why (silicon-based) alternatives?

- Growth of embedded systems
  - Flexibility less key than performance and hardware efficiency
  - hand-designed ASICs are quite popular
  - FPGAs improving in performance and density
- Changing application domain
  - Multi-phased streaming applications

Silicon VLSI

- Geometric scaling in density/speed
  - 50%/year increase in density
  - 35-50%/year increase in system performance
- Low cost, high reliability, acceptable yield
- Improved transistor fabrication techniques
  - e.g., SOI reduces junction cap, allows for reduced voltage

Silicon VLSI (cont.)

- Supply voltage
  - Reduction in each process generation reduces power, and improves switching speeds.
- Integration creates new possibilities
  - Tremendous jump in system performance with each level of integration.
  - Mixed-mode system-on-a-chip (SoC) products

Limitations of Silicon

- Currently based on optical lithography
  - Must move to extreme UV or x-rays to improve pattern resolution
- Transistors are bulk devices
  - Rely on having many atoms in each region
  - Becomes impossible to lightly dope regions close to 10nm feature size

Limitations of Silicon (cont.)

- Interconnects
  - Don't scale well with process shrink (relative delay increases)
  - Becoming a limiting factor in system speed.
  - Approaching 85% of overall delay
- Supply voltage
  - Using lower voltage reduces noise margins.

Non-Silicon Alternatives

- Molecular/Quantum Electronics
  - Essentially replace FETs with other devices that have similar behavior
- Carbon Nanotubes
  - Can get switch-like behavior, make wires
- Quantum Computing
  - Expose quantum effects to the programming model
  - Offers potential for performance that's impossible in conventional systems
- Biological Computing
  - Biological reactions mimic Boolean logic gates
  - Very slow, but may be useful for medical applications